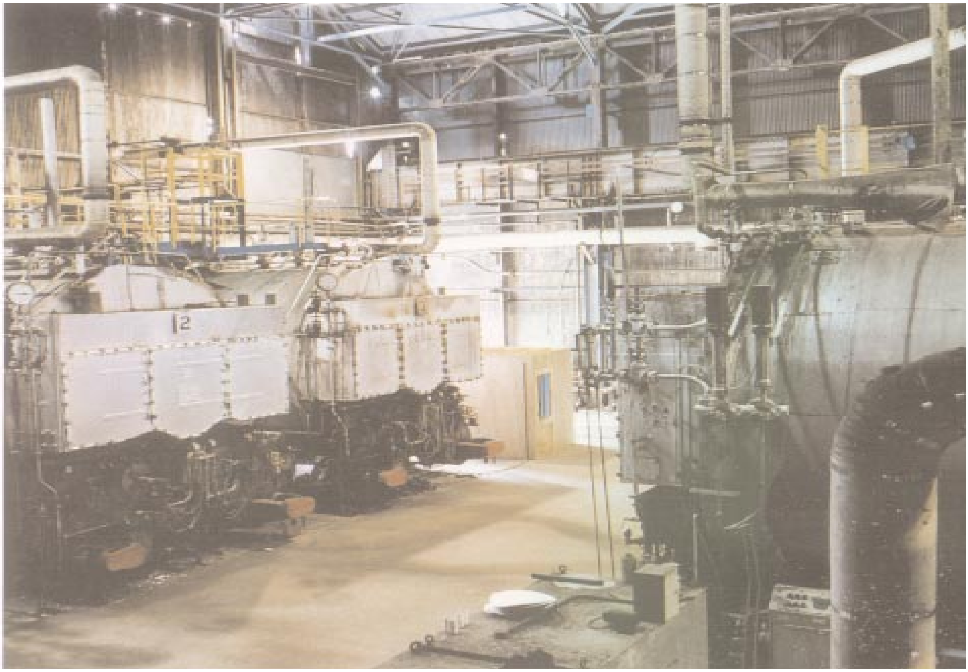
FUEL EFFICIENCY BOOKLET 14

Economic use of oil-fired boiler plant



ENERGY EFFICIENCY

BEST PRACTICE PROGRAMME

CONTENTS

INTRODUCTION

1 INTRODUCTION

Steam and pressurised hot water boiler plants in industry and commerce vary in capacity from 100 kW to over 30 MW (341,000 BTU/h to over 102 million BTU/h). This booklet relates mainly to shell boilers, i.e. those covering the middle range of capacity, of which there are many thousands in operation for heating and process applications. Much of the information is also relevant to other types of boilers.

The booklet provides guidance on the ways in which oil, and therefore money, can be saved in the operation of boiler plants. The approach used examines the plant from oil delivery, progressively through to the final heat output, and identifies and quantifies the various losses. Finally, there is a check list of money saving procedures.

In order to show savings in perspective, reference is made to an example plant having an oil bill of £250,000 per year. Individual cases obviously need their own examination, but nevertheless it is hoped that the inclusion of a quantitative example will help to give an indication of the possible savings that users can make.

Many boiler plants are operating at lower efficiencies than can be achieved and, moreover, maintained. The potential savings in oil can be worthwhile. This booklet will tell you how to obtain them.

2 BACKGROUND INFORMATION

Delivery, handling and storage

1 Fuel oils need to be heated for handling and storage purposes. Heavy fuel oil is normally delivered at a temperature of 50°C or higher, and should be kept and transferred at the recommended temperatures given in Table 1. Medium and light fuels will be delivered at minimum handling temperatures. Heating the oil in tanks and pipes above the temperature needed for storage and handling should be avoided as this wastes energy.

Steam traps on the tank and outflow heaters should be regularly maintained. It is advisable not to return hot fuel oil from a ring main

Table 1 Recommended storage and handling temperature (extracted from BS 2869)

Grade of fuel	BS 2869 Part 2: 1988 Classification	Minimum temperatures* Storage	Minimum temperatures* Handling
Light fuel oil	Class E	10°C	10°C
Medium fuel oil	Class F	25°C	30°C
Heavy fuel oil	Class G	40°C	50°C

** These minimum temperatures refer only to oils to specific standard classification. For different grades of fuels, particularly some of the heavier oils now available, the supplier should be referred to for the correct storage/handling temperatures.*

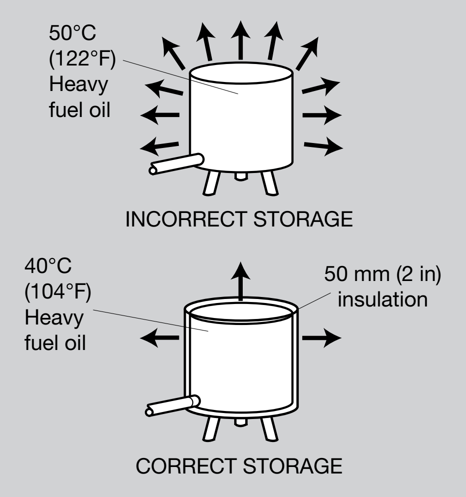
BACKGROUND INFORMATION

system back to the fuel storage tank, as this can give rise to excessively high and uncontrolled storage temperatures. In addition, it wastes energy and can seriously degrade the fuel, causing subsequent combustion problems. It is recommended that such fuel is recirculated back to the suction side of the pump.

2 All tanks and oil pipes in the open should be insulated and weather-proofed (Fig 1) and steam or electric tracing applied to oil pipes to maintain the minimum handling temperatures.

On vertical tanks, insulation should not reach ground level; 300 mm (12 in) clearance will prevent standing water soaking into the insulation and destroying its insulating properties.

Fig 1 Heat loss from storage tanks



Storage temperatures should remain at the recommended levels if 50 mm (2 in) of insulation is used on oil storage tanks, with very little, if any, heating required. Increasing the storage temperature above that recommended will result in unnecessary heat loss. The outflow heater should provide the extra heat necessary to raise the oil to the minimum handling temperature.

Oil line steam tracing needs to be checked frequently for leaks and damage, and electric tracing should be inspected for continuity.

3 Care should be taken during the discharge of tankers to avoid spillages through careless operation or faulty fittings. Oil suppliers insist that it is the purchaser's responsibility to ensure that there is sufficient space for delivery in the relevant tank, and that the filling pipes are properly labelled with the grade of fuel oil. The most economical way of buying oil is to take a full tanker load.

4 The oil level indication must be accurate, especially when fuel stocks are high.

5 Redundant fuel lines in the storage area should be removed, as they increase the risk of accidental injury, damage and spillage of oil.

6 There should be duplex oil filters in the fuel oil line, and these need to be cleaned regularly. Oil burner filters should also be regularly checked. Filter sizes should

BACKGROUND INFORMATION

follow recommendations given in BS 799: Part 4.

7 Frequent checks should be made to find any fuel leaks from tanks and pipes. Leaks should be promptly stopped as, apart from being wasteful, they can cause accidents and pollution, and are also a fire risk.

Pollution control

Energy savings cannot be looked at in isolation and must not be achieved at the cost of increased waste emissions.

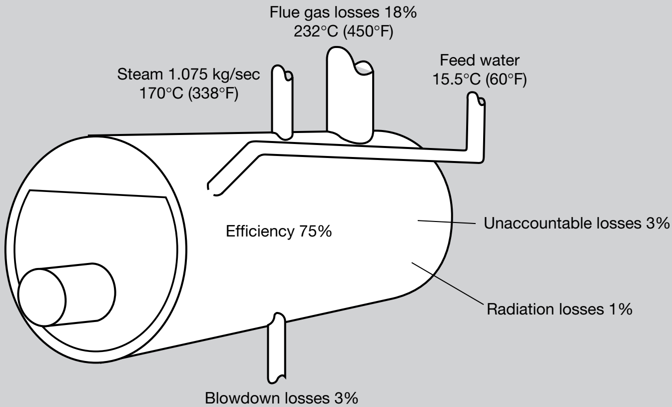
Depending on their size, boilers are dealt with by either the Clean Air Act Regulations or the Environmental Protection Act. Boilers under 20 MW come under the Clean Air Act, whilst boilers in the size range 20 - 50 MW are covered by Part B of the Environmental Protection Act (EPA). The Environment Agency is now responsible for larger boilers where aggregated fuel inputs exceed 50 MW on a net calorific value basis. With the implementation of the EPA, a requirement for BATNEEC (best available techniques not entailing excessive cost) is now enforced, replacing the previous best available means. In setting emission limits, the Environment Agency takes into account the costs of installing further pollution abatement equipment. If this is viewed to be excessive, then further control may not be required.

3 FACTORS AFFECTING THE EFFICIENT USE OF ENERGY

Example boiler

An Example Boiler (Fig 2) is used in the following sub-sections to illustrate the significance of savings.

Fig 2 Example boiler



Cost of £250,000 per year

FACTORS AFFECTING THE EFFICIENT USE OF ENERGY

It is recognised that modern boilers which are well maintained and controlled achieve efficiencies of over 80% (gross C.V.) on a regular basis. For the purposes of this booklet, it was assumed that 75% was a reasonable figure, when taking into account day-to-day fluctuation in output and outage. The boiler details are as follows:

Boiler efficiency based on gross calorific value:

Flue gas losses	18%
Radiation losses, unaccountable losses, etc.	4%
Blowdown loss (steam raising only)	3%
Boiler efficiency	100 - 25 = 75%
Flue gas temperature	232°C (450°F)
Feed water/boiler water return temperature	15.5°C (60°F)
Average steam production	1.25 MW (7,000 hours/year)
Operating pressure	7 barg (100 psig)
Steam temperature	170°C (338°F) (dry saturated)
Cost of heavy fuel oil	£250,000 per year
Price per litre	11p
Number of litres used per year	2,182,500

Boiler thermal efficiency

Minimum costs are achieved by running boilers at high thermal efficiency. This section examines the various losses and draws attention to how they can be minimised.

The heat losses from boilers include: losses from the flue gases, referred to as the flue gas loss; losses from the outside of the boiler, referred to as radiation losses; other incidental losses; and losses through blowdown. This can be expressed in basic equation form:

Boiler thermal efficiency % =
100% - (flue gas losses % + radiation losses % + incidental losses % + blowdown losses %)

Calculations in this booklet are based on the gross calorific value of the fuel. Where the heat content of fuels or boiler efficiencies are quoted, it is important to be clear whether they are on a gross or net basis. It is essential to understand these terms.

All fuels contain some hydrogen which when burned produces water in the form of steam. The latent heat in this steam is not recovered unless condensation occurs. The gross calorific value includes all of the available heat, whereas the net value is the gross less the heat in the water vapour. When gross values are used in the above equation, the flue loss item includes the heat in the steam. When net values are used this heat loss is excluded.

For this reason a boiler efficiency on a net

FACTORS AFFECTING THE EFFICIENT USE OF ENERGY

basis is numerically higher than that on a gross basis, although the actual heat output is identical. Net values are frequently used in most European countries.

For calculations like those in this booklet, the gross value is used because it is the simplest to correlate to fuel costs which are related to a gross calorific value. The difference between gross and net values is on average approximately 5.5%.

Flue gas losses

Fuel-to-air ratio

To achieve a high thermal efficiency, thereby minimising fuel costs, the amount of combustion air should be limited to that necessary to ensure complete combustion of the oil. In practice, some excess air, around 15 - 25%, will be needed; the actual amount required to give the optimum boiler efficiency will depend on the fuel used, the type of boiler and its burner, its method of operation and the effectiveness of the combustion equipment.

Heat is transported to the flue by the excess air. Consequently, if the air rate is too high, the loss of heat to the flue, and therefore the running cost, will increase. Similarly, if the air rate is too low a proportion of the fuel will remain unburnt, smoke will be produced, possibly breaching pollution regulations, and the running cost will again be increased. The boiler or burner supplier should be consulted to find out the best settings.

Provided that the burners are clean and well maintained, the fuel oil-to-air ratio controls on modern boilers should be able to maintain the recommended excess air through much of the turndown ratio of the burner, but the excess air will increase at low turndown rates.

Traditionally, modulating burner fuel-to-air

Savings or losses due to changes in efficiency

Simple calculations reveal possible savings or losses due to changes in efficiency. Given the efficiency values, the effect on the fuel cost is as follows:

$$\text{Change in fuel cost} = \text{original fuel cost} \times \frac{\text{new efficiency} - \text{original efficiency}}{\text{new efficiency}}$$

Taking the Example Boiler with an efficiency of 75%, if the efficiency is raised by 4% to 79% the saving would be:

$$\text{Fuel cost saving} = £250{,}000 \times \frac{79 - 75}{79} = £12{,}658$$

If a boiler with the same fuel consumption as the Example Boiler had an efficiency of only 50%, then an increase in efficiency to 54% would give a greater saving:

$$\text{Fuel cost saving} = £250{,}000 \times \frac{54 - 50}{54} = £18{,}519$$

FACTORS AFFECTING THE EFFICIENT USE OF ENERGY

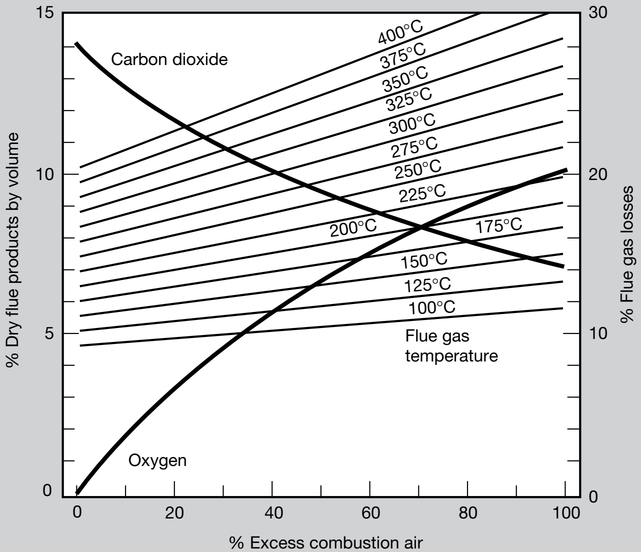
ratios are controlled by characterising cams and connecting linkages. These are subject to wear and tear, and it is important that repairs and adjustments are undertaken on an ongoing basis. Furthermore, where dual fuel burners are in operation, any changeover from one fuel to another necessitates recommissioning of fuel-to-air ratios, to ensure that combustion efficiency is not adversely affected.

Modern technology enables fuel-to-air ratios to be maintained at recommended levels at all times, ensuring consistent combustion efficiency. Microprocessor controlled servo motors fitted to fuel valves and air dampers replace the traditional methods of control, providing a programmable system which will automatically select and maintain the fuel-to-air ratio specific to a particular fuel.

On larger boiler plants operating under high load conditions, it will often prove economic to fit automatic fuel-to-air ratio controllers (oxygen trim controllers) which will maintain boiler efficiency. These continually monitor the level of oxygen in the flue gases and make corrections to the combustion air supply to maintain optimum conditions.

To check that the fuel-to-air ratio is correct, the usual method is to analyse the flue gases leaving the boiler. By finding out the composition and temperature of these gases, the losses to the flue can be assessed. These losses can be calculated using equations, such as those in BS 845: 1987 - Methods for assessing thermal performance of boilers for steam, hot water and high temperature heat transfer fluids. Alternatively, loss values can be read from

Fig 3 Flue gas losses, medium fuel oil



FACTORS AFFECTING THE EFFICIENT USE OF ENERGY

reference charts, such as those shown in Figs 3 and 5 which are sufficiently accurate for the aims of this booklet.

The charts show that the dry flue gas products volume is measured at ambient temperature and relate to medium fuel oil; for other types of oil the difference in boiler efficiency will be less than half of one per cent.

It is important to be aware of the limitations facing the boiler operator when operating close to stoichiometric air/fuel ratios in relation to stack solid emissions. A stoichiometric air/fuel ratio is where the amount of air present is just sufficient for complete combustion. The rate at which unburnt carbon is formed in heavy fuel oil fired plant is dependent upon:

- the amount of excess combustion air;
- the combustion chamber firing intensity;
- the quality of atomisation of the fuel;
- the quality of fuel/air mixing;
- the amount of asphaltenes in the fuel.

The stack solid emissions are affected by:

- excess air, which can chill the carbon particles in the flame;
- fuel atomising viscosity;
- the asphaltenes content of the fuel.

The effect of these parameters is summarised in Fig 4, which demonstrates that when using heavy fuel oil, there is an optimum value for the percentage of excess air to give minimum stack losses.

Flue gas analysis

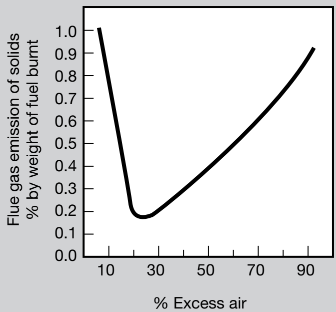
Typical operating conditions for efficient oil-fired operation are about 15 - 20% excess air at full load, giving 13 - 14% carbon dioxide (CO_2) in the flue gas, although excess air can increase to 30% at low fire.

The CO_2 or oxygen (O_2) concentration in the flue gas is important. Either gas can be readily monitored to ensure that the level of excess air is being properly controlled (see Fig 3).

The performance and efficiency of boilers should be regularly checked with a flue gas CO_2 or preferably O_2 analyser and a flue gas thermometer. These can be obtained in portable kits costing between £1,000 and £2,000. Some of the portable analysers available automatically compute boiler efficiency, giving flue gas temperature, excess air, carbon dioxide and efficiency at the touch of a button. Portable kits giving readings of nitrous and sulphur oxides (NO_x and SO_x) are also available and cost around £5,000.

When using analysers, it is most important that the maker's operating

Fig 4 Typical relationship between excess air and stack emission for a cylindrical fire tube boiler



Fuel HFO 3% asphaltenes combustion chamber intensity 1.5 MW/m³.
Showing increase in emission due to decreasing oxygen concentration and insufficient combustion chamber residence time.

FACTORS AFFECTING THE EFFICIENT USE OF ENERGY

instructions are complied with and that the instruments are properly serviced.

The greater expense of a permanent installation or the use of more expensive equipment may be justified for larger plant, or where there are several boilers. Testing for carbon monoxide may be recommended by the boiler or burner supplier; in particular, measurement of this gas together with oxygen should be considered with automatic boiler control.

When using a portable kit, the flue gas samples should not be diluted by air inleakage which would alter the flue gas analysis. In addition, the sample points should be thoroughly purged before aspirating the sample, to ensure that the sample tube is free from air and not obstructed.

Many boilers have no sample point, but on packaged units this can easily be provided by drilling a small hole in the metal outlet, as close to the boiler as practicable. Care should be taken to ensure that the sample is representative of the flue gas, by traversing across the flue and assessing and correcting for any variations in CO_2 or O_2.

On some old-type brick set boilers there may be difficulty in finding a suitable sample point which is unaffected by air ingress. Providing a sample point on these boilers may give rise to considerable re-pointing and sealing work.

Note that in practice the flue gas temperatures may drop as the percentage of CO_2 rises.

Cleanliness of heat transfer surfaces

If the boiler smoke tubes become fouled by soot and deposits, the amount of heat transferred from the hot flue gases to the water is reduced. This results in an increase in the temperature of the flue gases and, therefore, the flue gas losses, as shown in Fig 7. Boiler smoke tubes should be regularly cleaned to minimise the flue gas temperature rise.

It is helpful to install a permanent exit gas temperature recorder. When this shows an increase of around 20°C above that temperature for a clean boiler, the tubes must be cleaned.

A rise of 17°C causes a decrease in efficiency of one percentage point. Boilers operating at low load which are frequently turned on and off need cleaning more often than those which operate continuously.

Savings or losses due to flue gas composition change

If, in the Example Boiler, circumstances allowed the percentage of CO_2 in the flue gas at 232°C (450°F) to be increased from 9.8 to 13.5%, the flue gas losses would be reduced. The boiler efficiency would be improved by 3% to 78% resulting in a saving in the fuel bill of:

$$£250,000 \times \frac{(78 - 75)}{78} = £9,615 \text{ per year}$$ (see Fig 6)

This example is illustrated on Fig 5 to show how the graph is used

FACTORS AFFECTING THE EFFICIENT USE OF ENERGY

Fig 5 Flue gas losses, based on gross calorific value and an ambient temperature of 20°C

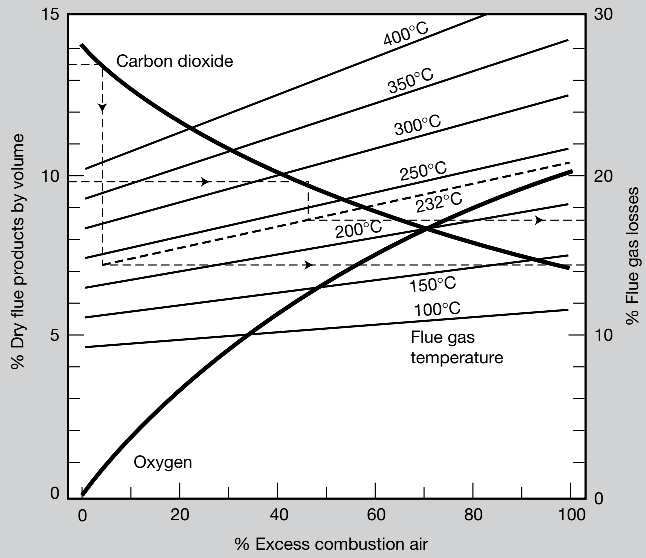
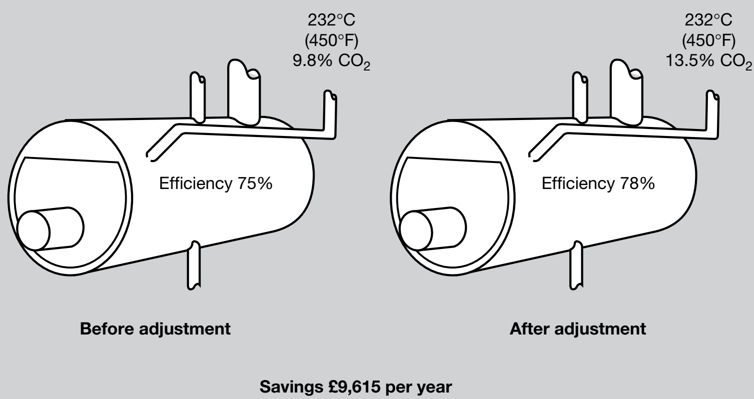


Fig 6 Change in efficiency due to flue gas composition change



FACTORS AFFECTING THE EFFICIENT USE OF ENERGY

Fuel additives and fuel saving devices

Fuel additives and simple fuel economy devices are periodically offered for use with boilers.

If a boiler is operated as efficiently as possible, i.e. with correct attention to combustion and other aspects mentioned in this booklet, there will be little scope for significant further improvement in thermal efficiency.

Fuel additives are not believed to produce energy savings; however it is recognised that there may be some operational benefits, particularly in cold weather.

Example showing the effect of fouled heat transfer surfaces

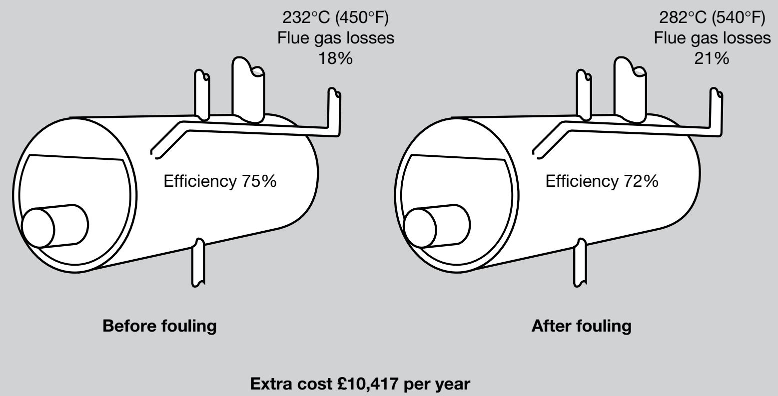
A 50°C rise to 282°C (540°F) in the temperature of the flue gas containing 9.8% CO_2 will cause an increase in flue gas losses to 20%. For the Example Boiler, this would reduce efficiency by 3%, at an extra cost of:

$$£250,000 \times \frac{72 - 75}{72} = £10,417 \text{ per year.}$$

Economisers

Economisers were widely used until the advent of extensive oil-firing in the 1950s, to pre-heat the feed water to steam boilers or the return water to water heaters. With fuel oil, the high dewpoint of sulphuric acid in the exhaust gases resulted in the very rapid corrosion and failure of the economiser, on which the acid condensed. Thus the use of economisers on oil-fired industrial and commercial boilers is not normally a practicable proposition, although they are increasingly being used with gas firing, where the acid dewpoint problem is diminished.

Fig 7 Change in efficiency due to flue gas temperature change



FACTORS AFFECTING THE EFFICIENT USE OF ENERGY

Fig 8 shows the typical corrosion curve for a fuel oil and indicates two temperature bends where severe corrosion will occur:

- around the acid dew point, where concentrated acids chemically attack the metal;
- around the water dew point, at which point the acids are much diluted and become even more corrosive.

Flue dampers

It may be economic in some cases to fit isolating dampers to individual boiler flues. In order to estimate savings, consideration should be given to the combination of boiler schedules and flue conditions, and suppliers should be consulted. Where dampers are fitted, safety interlocks must be fitted to ensure that the burner is not started up against a closed flue and that the system is adequately purged. See BS799 Part 4 : 1972, paragraph 4.6.5. Safety Interlocks for further details.

Radiation loss

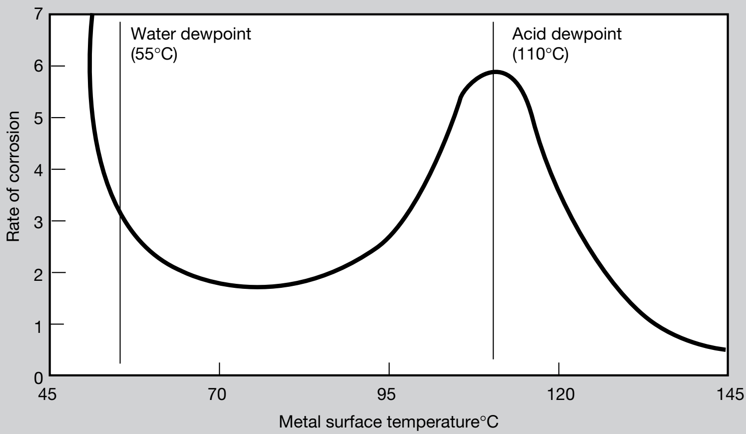
Radiation loss refers to heat loss from the surface of the boiler. It is better defined as radiation and convection loss, but only the term radiation is normally used in this context.

Radiation loss on modern boilers is usually less than 1% of the heat input at maximum rating. It may, however, be considerably higher on older boilers and it can be as high as 10% where insulation is in poor condition and the boiler design is old.

Radiation loss is not readily measurable on a boiler; however, experience has shown that in the case of conventional designs, these losses fall within ranges for the various types of boiler. These ranges are listed in BS 845: 1987. Other principal heat losses included with radiation in this booklet are those due to unburnt gases (mainly carbon monoxide) in the flue gas and unburnt carbon.

Radiation loss is constant whilst the boiler is

Fig 8 Corrosion curve - Fuel Oil



FACTORS AFFECTING THE EFFICIENT USE OF ENERGY

firing, and if it is running under low-load conditions this loss represents a higher proportion of the total fuel used than under high fire conditions.

Example of the effect of part-load running

If the load in the Example Boiler is supplied by two boilers running part-loaded at half of their maximum rating, and the true radiation loss is 4% at full load, then the total radiation loss will be doubled to 8%; this will add an extra £10,000 (4% of £250,000) to the annual fuel bill, compared with the situation where the load is supplied by one boiler at full load.

Firing schedule/boiler sequence control

The quantity and profile of the heat required by a plant throughout the day and week should be reviewed frequently, and the minimum number of boilers used to supply the demand. It may be worth risking temporary loss or reduction of steam supply in the event of a boiler failure in order to run at optimum efficiency. An assessment should be made of the time required either to bring a standby boiler on-line or to rectify likely faults.

Where multi-boiler plant installations are in operation, significant fuel and energy savings can be made by installing a Boiler Sequence Control System. These are fully automatic, microprocessor-controlled systems which monitor and sequence on/off operations of boilers and associated equipment according to steam demand.

The valving off of boilers not in continuous use should receive periodic examination. Valves isolating one boiler from another sometimes pass steam when closed, and require regular maintenance to prevent leakage into standing boilers. If boilers are required to stand for long periods, blanks should be inserted into the flanges next to the valves.

Centralised integrated control of boiler plant

A centralised control system is a combination of specific microprocessor control systems, such as those previously referred to, comprising fuel-to-air ratio control and oxygen trim, coupled with a diagnostic system which indicates boiler and associated boiler plant faults. The advantages of centralised control are numerous, enabling all aspects of boiler plant operation to be optimised simultaneously. Maximum overall efficiency is therefore maintained and boiler down-time is kept to a minimum.

Variable speed control of combustion air fan

If the load characteristic of a large boiler plant is variable, then substantial energy savings are possible using a Variable Speed Drive (VSD) system.

A VSD system will reproduce the operating characteristics of a fixed speed combustion air fan and adjustable damper arrangement, as well as reducing the average electrical demand of the fan motor by approximately 60%. The use of a VSD system has been shown to be cost-effective whilst at the same time maintaining good combustion conditions and high boiler efficiency. See Good Practice Case Study 35 - *Variable speed drive on a boiler fan* - for details of an industrial application, showing the savings achieved.

FACTORS AFFECTING THE EFFICIENT USE OF ENERGY

Combustion air pre-heat

Combustion air pre-heat is another potential energy-saving technique worthy of consideration. The usual heat sources for combustion air pre-heating include:

- heat remaining in flue gases;
- higher temperature air drawn from the top of the boilerhouse;
- heat recovered by drawing air over or through the boiler casing to reduce shell losses.

The thermal efficiency of a boiler plant could be increased by 1% if the combustion air temperature was raised by a further 20°C.

Blowdown

It is necessary to blowdown boilers regularly either:

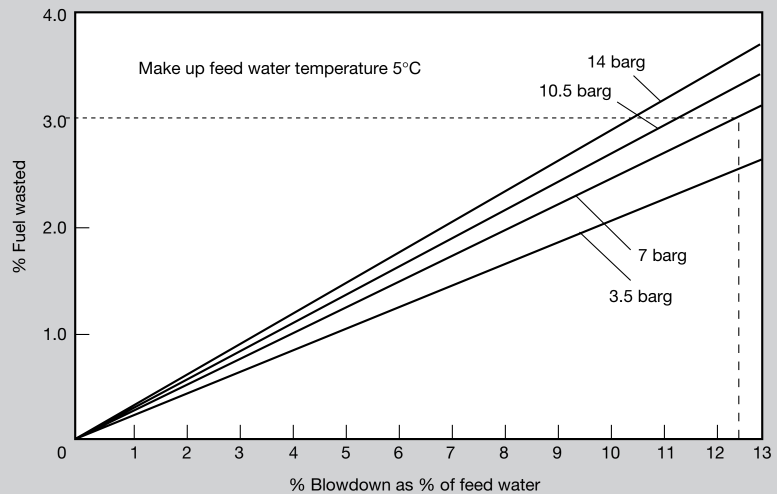
- from the bottom of the boiler, to remove sludge composed of precipitated salts;

and/or:

- from the side of the boiler, to maintain the level of total dissolved solids (TDS) at levels laid down in BS 2486: 1978, thus avoiding priming and carry-over into the steam mains.

To avoid unnecessary loss of heat, the level of blowdown should be kept as low as possible while still maintaining the recommended level of TDS. The use of heat loss from blowdown for some useful purpose should be considered, e.g. to pre-heat feed water. The rate of heat loss due to blowdown is shown in Fig 9.

Fig 9 Heat loss due to blowdown



FACTORS AFFECTING THE EFFICIENT USE OF ENERGY

A high blowdown loss may well justify expenditure on heat recovery equipment or water treatment plant. If all the factory condensate is returned to the hot well, blowdown can be drastically reduced.

Example of the effect of blowdown

In the case of the Example Boiler, blowdown accounts for 3% of the losses in the boiler. This represents blowdown of approximately 12.5% of the evaporation rate which is also approximately 12.5% of the feed water, and costs £8,600 per year in lost fuel, plus the cost of the feed water and the water treatment where applicable. This example is indicated on Fig 9 to show how the graph is used.

Where more than one boiler is operated on an intermittent system, it is advantageous to stagger or automatically time the blowdown cycle in order to spread the availability of waste heat more evenly. This will enable waste heat recovery to be more economic, because the equipment required will be smaller and will run for a higher proportion of the time, thereby proving more cost-effective.

One of the most simple ways to recover heat from blowdown is through direct use of the flash steam, which forms due to evaporation as the pressure falls through the blowdown valve. This is pure water, with no dissolved solids, and can therefore be added directly to the make-up water for the boiler. Additional heat can be recovered from the remaining blowdown by installing a heat exchanger to pre-heat boiler feed water. (Fuel Efficiency Booklet 2 - *Steam* - covers this subject in greater detail.)

Water treatment

Water treatment is necessary with all water to:

- prevent scale formation in boilers and ancillary equipment which may cause the boiler metal to overheat and fail disastrously (Fuel Efficiency Booklet 2 - *Steam* - gives examples of heat transfer being affected by the formation of scale);
- control sludge and scale formation in the boiler, and to reduce blowdown;
- reduce or eliminate corrosion of the boiler and steam mains (from carbon dioxide in the steam) which leads to higher maintenance costs;
- avoid contamination of the steam by boiler water, which can be carried over due to foaming and priming;
- minimise corrosion in the boiler due to dissolved oxygen in the feed water.

Adequate treatment should be given, following the advice of a competent water treatment specialist. Over-dosing can be avoided by ensuring that operatives are not heavy handed and by switching off treatment pumps when boilers are not operating. Ideally, boiler-dosing equipment should be controlled by the operation of the feed water pump.

The water treatment facilities should be appropriate to the requirements. To ensure this, more than one opinion and quotation should be obtained from water treatment firms, the boiler manufacturer and from the insurance company. The cheapest is not necessarily the best buy. Most of the water treatment should be carried out in plant external to the boiler.

FACTORS AFFECTING THE EFFICIENT USE OF ENERGY

If the quality of the water treatment is improved and/or the proportion of returned condensate is increased, this should reduce the amount of blowdown necessary. Total dissolved solid levels are easily checked by measuring water density (using a special hydrometer) and temperature. Boiler water test kits are cheap and relatively easy to use, and can be purchased through a water treatment specialist. Detailed recommendations on treatment can be found in BS 2486: 1978 - *Recommendations for treatment of water for land boilers.*

Condensate recovery

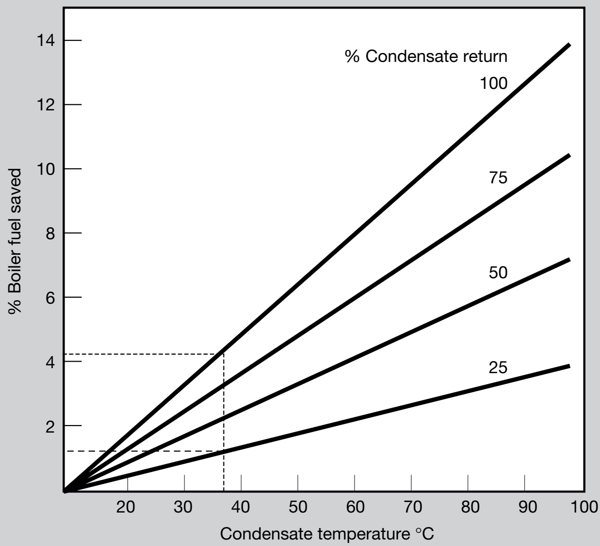
If the feed water temperature is low, the cause should be discovered. It could be due to:

- a low rate of condensate return;
- the lack of insulation on the condensate return pipes (though this may not be important in systems used exclusively for space heating);
- losses from the feed tank water either as heat through the walls or as overflows.

As much condensate as is economically possible should be returned from sources where there is no likelihood of contamination. This will save heat, make-up water and any chemicals used in water treatment, as well as reducing blowdown losses. The possible fuel savings resulting from increased condensate return are shown in Fig 10.

Where there is a danger of feed water contamination, automatic dumping by measuring the conductivity of the condensate is common. The monitors should be sited so that only the contaminated condensate supply is

Fig 10 Fuel saved by condensate return



FACTORS AFFECTING THE EFFICIENT USE OF ENERGY

dumped and not the whole of the condensate stream. In large, multiple installations it may be necessary to monitor and dump each condensate source independently. Contaminated condensate can cause both corrosion in boilers and carryover, and must therefore be avoided.

Without special arrangements, it is rarely possible to use feed water in excess of 82°C (180°F) due to cavitation problems on the feed pump. The feed water temperature can, however, be raised above this level after the pump if an economiser is fitted. When in doubt, the boiler or feed pump manufacturer should always be consulted. Good Practice Case Study 153 - *Differential drainage and boiler return system* - assesses the effectiveness of returning condensate directly to the boiler.
Fuel Efficiency Booklet 2 - *Steam* - has a section on heat recovery techniques which covers this subject in more detail.

Example of the possible savings from increased condensate return

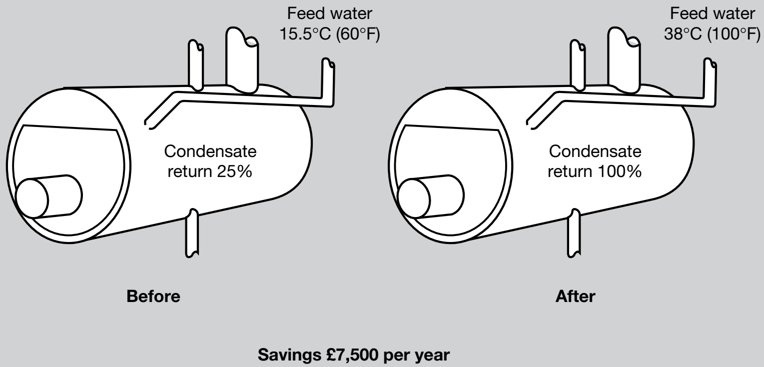
If the feed water temperature in the Example Boiler is raised from 15.5°C (60°F) to 38°C (100°F) by increasing the amount of condensate returned at 38°C (100°F) from 25% to 100%, a saving of 3% of boiler will result, worth £7,500 per year (see Fig 11). Further savings will also accrue due to an accompanying reduction in blowdown losses.

Steam and hot water services

Steam supply

Steam boilers should not be operated below the minimum pressure recommended by the manufacturer. If the steam-using equipment requires a significantly lower pressure, consideration should be given to de-rating the boiler or replacing it. Alternatively, the high pressure steam could be used in a steam turbine to generate electricity. These actions will

Fig 11 Change in operating cost due to extra condensate return



FACTORS AFFECTING THE EFFICIENT USE OF ENERGY

minimise distribution heat losses. The pressure drop in the main steam lines up to the point of use will need to be checked so that the optimum initial pressure can be determined. A safety valve will be needed on the downstream side to protect those parts of the system operating at the lower pressure.

Header connections on boiler plant

Where more than two boilers are connected into a common header it is important that the layout is correct. Fig 12 shows correct and incorrect methods of connecting four boilers into a header.

Incorrect connection can lead to the following sequence of events occurring. One or more boilers could receive an excess steam demand of up to 25%, e.g. boilers 3 and 4 in Fig 12a. Due to limited heat input, the boiler(s) will respond to this demand with a drop in pressure, accompanied by an expansion of the steam and water mixture in the boiler, resulting in foaming and carryover. In severe cases this can cause loss of water from boilers, leading to boiler lock-out due to low water, with the load then being thrust upon the remaining boilers. These in turn will become overloaded and the system cascade, locking out all the boilers at a time when their outputs are all needed. This effect is caused by the pressure loss along the header, which increases proportionally with the square of the steam flow.

In Fig 12a, the pressure in the header will fall severely from the point of connection at boiler 1 to those at boilers 3 and 4, as the successive outputs of the boilers are added into the header; boilers 3 and 4 could become severely overloaded. The pressure difference, and hence boiler loading, between boilers 1 and 2 would be much less, about 5%, which the firing equipment could handle. To avoid problems, not more than two boilers should discharge into a header or sub-header, as shown in Fig 12b.

Many installations have boilers incorrectly connected to the distribution system, resulting in the problems described. It is worthwhile changing the connections to overcome these problems. As a temporary measure, the outlets from all boilers can be fitted with limiting orifice plates designed to lose about 3 bar pressure at full boiler rating.

Loading problems can exist with all boilers, irrespective of fuel used, and if allowed to persist can seriously affect the reliability and efficiency of the whole steam generating and using plant.

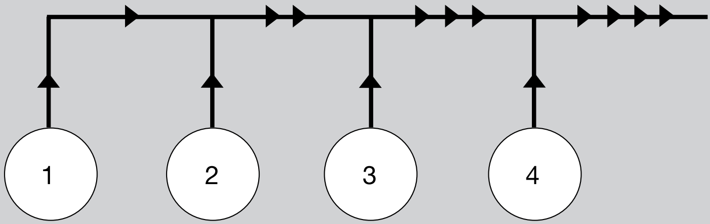
Pipework

All piping and valves conveying steam and condensate should be properly insulated and weatherproofed, except where they are exclusively part of a controlled heating system, and the steam supply should be turned off when there is no heating requirement. Insulating large diameter pipes pays off in a few weeks, and insulating small diameter pipes in a few months. Often in older installations steam valves and flanges were not lagged, but it is now economic to do so.

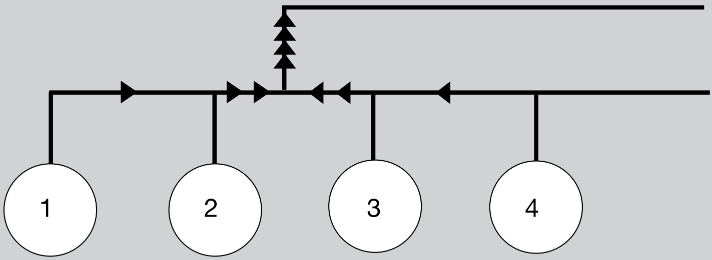
Procedures should be established such that insulation is examined regularly and promptly replaced where necessary, particularly on equipment or pipes which have had to be dismantled or repaired. The economic thickness of the insulation should be reassessed at replacement; some insulation contractors and equipment suppliers may still be working on uneconomic thicknesses. Further information

FACTORS AFFECTING THE EFFICIENT USE OF ENERGY

Fig 12 Methods of connecting steam boilers to a distribution system



(a) Incorrect method of connecting steam boilers to distribution system, causing exessive demand on boilers 3 and 4



(b) Correct method of connecting steam boilers to distibution system, demand on all boilers vitually balanced

can be found in Fuel Efficiency Booklet 8 - *The economic thickness of insulation for hot pipes*.

Where cavitation may result from increased water temperature due to insulating the feed water pipes, there should be an adequate head on the suction side of the boiler feed pump.

Example of the effects of insulation

In the Example Boiler, 30m (100ft) of unlagged 80mm (3in) pipe carrying steam at 7 barg (100 psig) and 170°C (338°F) will lose heat worth some £2,520 per year.

An uninsulated valve is equivalent to 1m (3 linear feet) of uninsulated pipe; at 7 barg (100 psig) an 80mm (3in) valve will lose heat equivalent to £84 per year. An uninsulated flange will lose half this.

CHECKLIST OF MONEY - SAVING PROCEDURES

4 CHECKLIST OF MONEY-SAVING PROCEDURES

1 Measure the output of steam from boilers either directly by means of a steam meter, or indirectly by metering the total boiler feed water and estimating the blowdown. The ratio of steam to fuel is the main measure of boiler efficiency and should be maintained at a level compatible with good practice.

2 Continuously log boiler performance so that signs of deterioration soon become evident, enabling corrective maintenance to be carried out. Examples of daily log sheets and weekly summary sheets for steam and hot water boilers are given in Figs 13, 14, 15 and 16.

3 Meter feed water.

4 Check steam meters occasionally, as their performance deteriorates with time due to erosion of the metering orifice or pitot head. Steam meters only give correct readings at the calibrated steam pressure - re-calibration is required if the steam pressure is changed, and the meter reading should be corrected for changes in steam volume. See Good Practice Guide 18 - *Reducing consumption costs by steam metering* - for more detailed information.

5 Isolate pipelines not in use and disconnect redundant pipes. Regular surveys should be made, particularly if the pipework uses are frequently changed.

6 Ensure that accounting for input and output of energy in boiler houses is as realistic as possible. Fuel stock-taking should be accurate.

7 Improve housekeeping procedures, as these are likely to result in better working conditions and morale in the boiler house.

8 Review the repair and maintenance procedures in the boiler house, especially where they affect the firing equipment, controls and instrumentation. There should be a regular routine for cleaning boiler heat transfer surfaces or smoke tubes. Any useful instrumentation or equipment which has fallen out of use, for example water meters, temperature indicators or recorders and economisers (where applicable), should be repaired and brought back into use.

9 Periodically check the state of furnace tubes and flues. In older boiler installations, underground flues may need to be checked for water inleakage.

10 Repair steam leaks without delay. Such leaks not only waste energy but are also potential safety hazards.

11 Consider entering a boiler maintenance agreement with the manufacturers.

12 Check oil storage temperatures to ensure that there is no overheating.

13 Frequently check oil line steam tracing for leaks and damage, and electric tracing for continuity.

14 Investigate the possibility of implementing heat recovery systems. See Good Practice Guide 30 - *Energy efficient operation of industrial boiler plant* - for more detailed information on available techniques.

5 ACKNOWLEDGEMENT

The Department of the Environment is grateful to the British Standards Institution for permission to reproduce material from BS 2869 Part 2: 1988.

CHECKLIST OF MONEY - SAVING PROCEDURES

Fig 13 Example daily log sheet for steam boilers

Date: | Plant:

Time	Boiler No	Steam		Water				Flue gases			Draught		Fuel					Air	Comments
		Pressure (bar)	Temp. (ºC)	Temp. econ. inlet (ºC)	Temp. boiler inlet (ºC)	Meter reading feed water (litres)	Meter reading make-up water (litres)	Temp. boiler outlet (ºC)	Temp. econ. outlet (ºC)	CO_2 or O_2 (%)	Pressure in combustion chamber (bar)	Pressure at boiler outlet (bar)	Flow meter ($kg.m^3$ or litres)	Return meter ($kg.m^3$ or litres)	Flow temp. (ºC)	Return temp. (ºC)	Ashes (kg)	Outside temp. (ºC)	
Total																			
No of readings																			
Average																			

Daily Summary

Fuel type and grade. . . . .
. . . .
Fuel used (metered). . . . .
Fuel used . . . . kg
Evaporation of steam: total . . . . kg
Ashes: total . . . . kg

Density (20/20)...
or Calorific Value ....kJ/kg or kJ/m^3
Fuel used (corrected to 20ºC)...
....
Evaporation of steam per kg of fuel.................................kg
= ....% of fuel

Feed water: Meter reading (start day) ....kg
Meter reading (end of day)...kg
Difference...kg
Make-up water ....kg = ...% of evaporation
Blowdown (total) time..Quantity

Operators on duty:	Shift 1	Shift 2	Shift 3	Comments

CHECKLIST OF MONEY - SAVING PROCEDURES

Fig 14 Example daily log sheet for hot water boilers

Date:								Plant:											
Time	Boiler No	Water						Flue gases			Draught		Fuel					Air	Comments
		Working pressure (bar)	Temp. boiler outlet (°C)	Temp. econ. inlet (°C)	Temp. boiler inlet (°C)	Meter reading feed water (kJ's or litres)	Meter reading make-up Water (litres)	Temp. boiler outlet (°C)	Temp. econ. outlet (°C)	CO_2 or O_2 (%)	Pressure in combustion chamber (bar)	Pressure at boiler outlet (bar)	Flow meter (kg.m^3 or litres)	Return meter (kg.m^3 or litres)	Flow temp. (°C)	Return temp. (°C)	Ashes (kg)	Outside temp. (°C)	
Total																			
No of readings																			
Average																			

Daily Summary

Fuel type and grade.	Density (20/20)..	Total Water circulation..litres
. . . .	or Calorific Value ....kJ/kg or kJ/m^3	Average temperature difference...................................°C
Fuel used (metered).	Fuel used (corrected to 20°C)....................................	Total heat output...kJ
Fuel used . . . . kg	....	Total heat per kg of fuel ....kJ
Evaporation of steam: total . . . . kg		Make-up water.................................litres = ... % of total
Ashes: total . . . . kg	= ....% of fuel	

Operators on duty:	Shift 1	Shift 2	Shift 3	Comments

CHECKLIST OF MONEY - SAVING PROCEDURES

Fig 15 Example weekly summary sheet for steam boilers

Week Commencing				Plant:			
Date	Fuel consumed (kg)	Ashes (kg or %)	Water evaporated (kg)	Evaporation per kg or m^3 of fuel (kg)	Make-up water (% of total)	Hours operating	Comments
Total							
No of readings							
Average							

Total amount of fuel used .... kg at £ ....per kg

.... litres (corrected to 20^0C) at £ .... per litre (or cubic metre = 10^3 litres)

Weekly total fuel costs £..

Costs of fuel for evaporating 1000 kg of water £...

Comments on weekly summary ....
....
....

WEEKLY SUMMARY SHEET - HOT WATER BOILERS

Fig 16 Example weekly summary sheet for hot water boilers

Week Commencing				Plant:					
Date	Fuel consumed (kg)	Ashes (kg or %)	Total water circulated (kg)	Average temperature difference (^{O}C)	Total heat output (kJ)	Heat output per kg or m^3 of fuel kJ	Make-up water (% of total)	Hours operating	Comments
Total									
No of readings									
Average									

Total amount of fuel used .... kg at £ .... per kg

.... litres (corrected to $20^{O}C$) at £ .... per litre (or cubic metre = 10^3 litres)

Weekly total fuel costs £...

Costs of fuel per MJ £ ....

Comments on weekly summary ....

....

....

SOURCES OF FURTHER INFORMATION

6 SOURCES OF FURTHER INFORMATION

■ *British Standards:*

BS 2869 Part 2: 1988 -
Specification for fuel oil for agricultural and industrial engines and burners (Classes A2, C1, C2, D, E, F, G and H)

BS 845: 1987 -
Methods for assessing thermal performance of boilers for steam, hot water and high temperature heat transfer fluids

BS799 Part 4: 1972 -
Atomising burners over 36 litres per hour and associated equipment for single burner and multi-burner installations

BS 2486: 1978 -
Recommendations for treatment of water for land boilers

Copies of these British Standards are available from:

British Standards Institution
Sales Department
Linford Wood
Milton Keynes
MK14 6LE

■ *DOE Publications:*

Good Practice Guide 18
Reducing energy consumption costs by steam metering

Good Practice Guide 30
Energy efficient operation of industrial boiler plant

Good Practice Case Study 35
Variable speed drive on a boiler fan

Good Practice Case Study 153
Differential drainage and boiler return system

Copies of these publications and other literature applicable to the economic use of oil-fired boiler plant are available from:

Energy Efficiency Enquiries Bureau
ETSU
Harwell
Didcot
Oxfordshire
OX11 0RA
Tel: 01235 436747
Fax: 01235 433066

Information is also available through regional Government Offices.

The latest news in energy efficiency technology

Energy Management is a free journal issued on behalf of the Department of the Environment which contains information on the latest developments in energy efficiency, and details of forthcoming events designed to promote their implementation. It also contains information addresses and contacts for the regional Government Offices.

Copies of *Energy Management* can be obtained through:

Emap Maclaren Ltd
Maclaren House
19 Scarbrook Road
Croydon
Surrey
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Titles in the Fuel Efficiency Booklet series are:

1 *Energy audits for industry*
1B *Energy audits for buildings*
2 *Steam*
3 *Economic use of fired space heaters for industry and commerce*
4 *Compressed air and energy use*
7 *Degree days*
8 *The economic thickness of insulation for hot pipes*
9 *Economic use of electricity in industry*
9B *Economic use of electricity in buildings*
10 *Controls and energy savings*
11 *The economic use of refrigeration plant*
12 *Energy management and good lighting practices*
13 *Waste avoidance methods*
14 *Economic use of oil-fired boiler plant*
15 *Economic use of gas-fired boiler plant*
16 *Economic thickness of insulation for existing industrial buildings*
17 *Economic use of coal-fired boiler plant*
19 *Process plant insulation and fuel efficiency*
20 *Energy efficiency in road transport*

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Further information

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Fax01235 433066
Helpline Tel 0800 585794
Helpline E-mail etbppenvhelp@aeat.co.uk

Energy Consumption Guides: compare energy use in specific processes, operations, plant and building types.

Good Practice: promotes proven energy efficient techniques through Guides and Case Studies.

New Practice: monitors first commercial applications of new energy efficiency measures.

Future Practice: reports on joint R & D ventures into new energy efficiency measures.

General Information: describes concepts and approaches yet to be fully established as good practice.

Fuel Efficiency Booklets: give detailed information on specific technologies and techniques.

Energy Efficiency in Buildings: helps new energy managers understand the use and costs of heating, lighting etc.